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To cite this article: G V Shimov and N I Bushueva 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **969** 012075

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Study of the Manufacturing Options for an Asymmetric Plate Made of 12X18N10T Steel

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Abstract. The analysis of possible options for manufacturing an asymmetric plate of 12X18N10T steel is presented. A phenomenological model of damage accumulation was used to analyse the probability of metal micro – and macro – destruction. The results of FEM modelling of technological processes of plate manufacturing are presented. Due to these results were made the conclusions about feasibility of their application based on the metal damage calculation. The choice of a rational technology to produce a plate is justified, in which the greatest metal ductility reserve takes place at a dangerous point. According to the proposed scheme, an experimental batch of plates have been made.

1. Introduction

The production technological scheme of any shaped profile is developed depending on the material, quality requirements, volume of the produced batch, profile configuration and specific production conditions. It is important to say that determining the optimal scheme for a group profiles manufacturing or a specific shaped profile is a demanding task requiring simultaneous consideration of variety factors. There are more and more scientific studies of technologies to produce metal products using the method of damage assessment [1–4] considered in the article due to the development of old criteria and widespread use of new criteria for destruction [5–15]. This paper uses the phenomenological theory of damage to predict the probability of damage at a point.

2. Research material and methodology

The theory and practice of manufacturing shaped profiles show [16] that with increasing axes of symmetry in the cross section of the profile, the manufacturing technology becomes easier. The monosymmetric profiles containing relatively thin webs are non-technical in most of the known schemes due to the complexity of editing the finished profiles in the cold state. The analysis and selection of the most suitable technological scheme for small-scale production of a monosymmetric thin-walled highly accurate profile made of corrosion-resisting steel type 18–10 for the plate is performed (Figure 1). The length ranged from 50 to 100 mm. The work's aim was to offer a rational technology for manufacturing this plate according to the requirements of the technical conditions.

The complexity of manufacturing is that the plate must have the increased head strength section of transition from the plate to the head in the “danger zone”. The reliability of the plate under reactor conditions is evaluated by both the full strength and metal ductility. The metal must remain ductile



throughout the operation cycle in the reactor. That is why the metal ductility reserve is very important performance in this case.

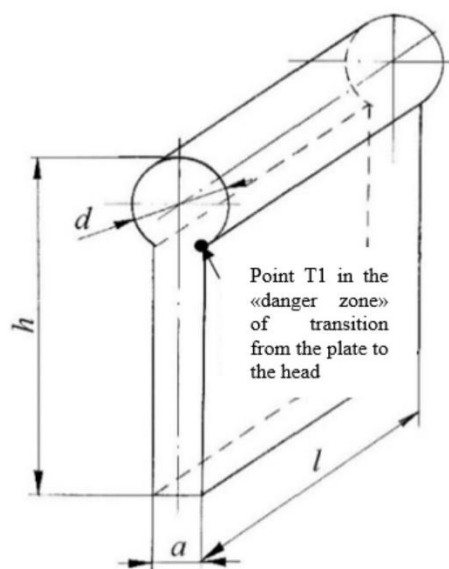


Figure 1. Shape and dimensions of the plate.

The possibility of obtaining a finished plate was evaluated during computer and physical modeling according to the methods mentioned above. Also, important to take into account the change of the accumulated degree of shear deformation, damage and metal ductility reserve in the “danger zone”.

3. Option for manufacturing the plate by rolling

Flat rolling is the traditional method of producing these types of profiles. This method provides the best performance in comparison with other one. The case of manufacturing a plate by rolling from a blank with a thickness of 3 mm and a length of 50 mm, the rolls diameter $D = 130$ mm was considered. The use of a double gauge is necessary to prevent the plate from bending (Figure 2). There is a need to separate the plates after rolling, which leads to inferior surface quality of the plate head.

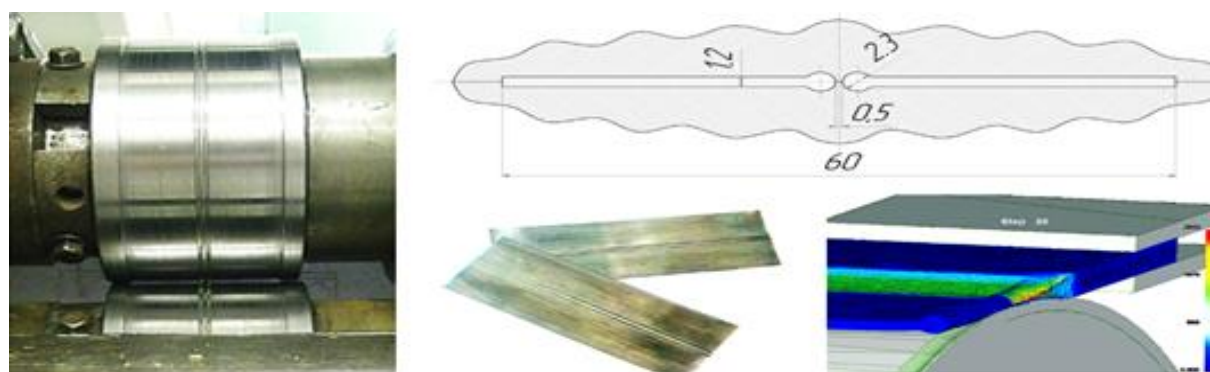


Figure 2. Gauge and sectors for rolling double plates and rolled plates on the laboratory mill Duo-130.

The FEM-modeling process problem in DEFORM-3D for the purpose of analyzing stress-strain state during rolling is solved. The 12H18N10T steel hardening curve was set tabular according to the literature data [17]. The elongation ratio across the plate λ_p is comprised 2.5. The elongation ratio across the head $\lambda_g - 1.78$. The rolling process modeling has shown that it is possible to produce a plate in one pass. Energy-power parameters of rolling are obtained as follows: rolling force $P = 1.06$ MN, pressure metal on the rolls $p = 1.89$ kN, mill torque $M = 8.59$ kN·m.

The resulting plates in shape and size fully met the requirements of the technical conditions. The difference between the rolling-out on the profile elements did not lead to a crescent-shaped strip due to the use of a double gauge. It can be concluded that the method is generally suitable for industrial use.

A phenomenological model of damage accumulation is used to analyze the probability of metal micro-and macro-destruction. The stress state indicator in the phenomenological theory of damage is used as integral characteristics σ/T , where $\sigma = (\sigma_{11} + \sigma_{22} + \sigma_{33})/3$; σ_{11} , σ_{22} , σ_{33} are principal normal stress, $T = (0.5 s_{ij} s_{ij})^{1/2}$ is the intensity of the tangential stresses, s_{ij} are deviator stress tensor components). The degree of shear deformation Λ is used as a generalized characteristic of the accumulated deformation of a material particle. This parameter is calculated along the trajectory of the particle moving [18].

The metal damage at the point has the additivity property ($\omega = \sum_{i=1}^n \omega_i$) and is determined at the time by the formula:

$$\omega = \int_0^{\Lambda} \frac{a \cdot \Lambda^{a-1}}{\Lambda_p^a} d\Lambda, \quad (1)$$

where a is the functional coefficient that characterizes the rate of metal damage accumulation, depending on the metal properties, Λ_p is the maximum permissible degree of shear deformation at the specified indicators of the stress state σ/T and μ_σ .

The functional coefficient a depends on the index σ/T and is calculated using the formula:

$$a = a_0^{1+\alpha\sigma/T} \quad (2)$$

where a_0 is the coefficient that depends on the grade of steel and corresponds to the a value when $\sigma/T = 0$, α is the power factor, $\alpha \approx 0,238$ for all steel grades [19].

The coefficient a_0 is determined experimentally when testing for alternating torsion at different pressures. For cold rolled steel sheet 12H18N10T $a_0 = 1,63$ [20].

The rolling process was divided into 10 time stages and in each time point was calculated values Λ_i , ω_i и Λ_Σ , ω_Σ accumulated over the period of the deformation point. An unfavorable stress-strain state was found in the "danger zone" when analyzing the results of rolling simulation. The components of stress and strain tensors were determined to estimate the metal ductility reserve in the transition zone from the plate to the head. The stress state index σ/T and the accumulated degree of shear strain Λ at T1 are also calculated.

The metal ductility reserve due to the presence of significant tensile stresses in the "danger zone" is relatively small after rolling ($\Lambda_\Sigma = 1.92$ when $\sigma/T = 0.32$). The reserve of metal ductility is found in the corresponding diagram $\Lambda_p = f(\sigma/T)$ [18], where Λ_p is the maximum permissible degree of shear deformation Λ_p . It is composing 2.31 at $\sigma/T = 0.32$ for 12H18N10T steel. The diagram of the dependence of the accumulated degree of shear deformation on the coefficient σ/T at point T1 and the ductility diagram for 12H18N10T steel [19] are presented in Figure 5. Curve 1 in Figure. 5 characterizes the dependence of Λ_p on σ/T and μ_σ , which is determined when testing samples on a high-pressure bench. Curve 2 in Figure 3 illustrates the process of accumulation in time of the degree of shear deformation Λ_i when the point T1 passes the deformation zone.

Damage at a danger point after rolling is composing $\omega_\Sigma = 0.28$. The damage value of 0,28 exceeds the first micro-fracture criterion ω^* (for steel 12H18N10T $\omega^* = 0.25$), which indicates the probability of micropores and micro-cracks in the "danger zone" [19]. The indicator σ/T is shifted to the positive region $\sigma/T = 0.32$ due to the resulting tensile stresses at the last stages of deformation (the moment of final head formation in the rolls). The metal ductility reserve is so small that there is a possibility of microcracks at the point of transition of the plate into the head of the plate in this stress-strain state scheme.

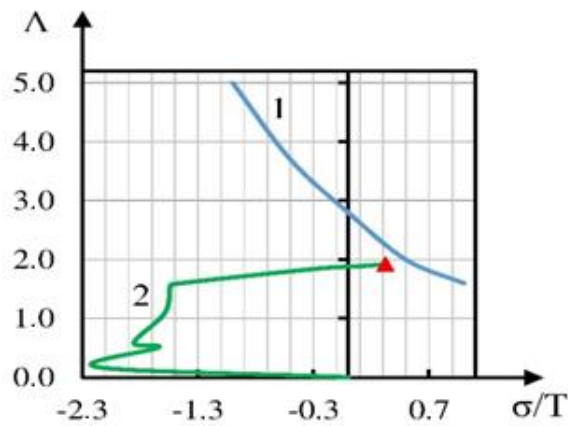


Figure 3. Dependence diagram of Λ on σ/T during rolling a plate in a double gauge: 1 – ductility diagram $\Lambda_p = \Lambda_p(\sigma/T)$ for 12H18N10T steel; 2 – dependence curve $\Lambda_i = \Lambda_i(\sigma/T)$ for point T_1 .

4. Option of manufacturing the plate by heading

An alternative production technology is heading due to the shape of the plate. The FEM-modeling task of the process in DEFORM-3D was set and solved for the purpose of analyzing stress-strain state during heading. The heading process was also divided into 10-time stages (Figure 4).

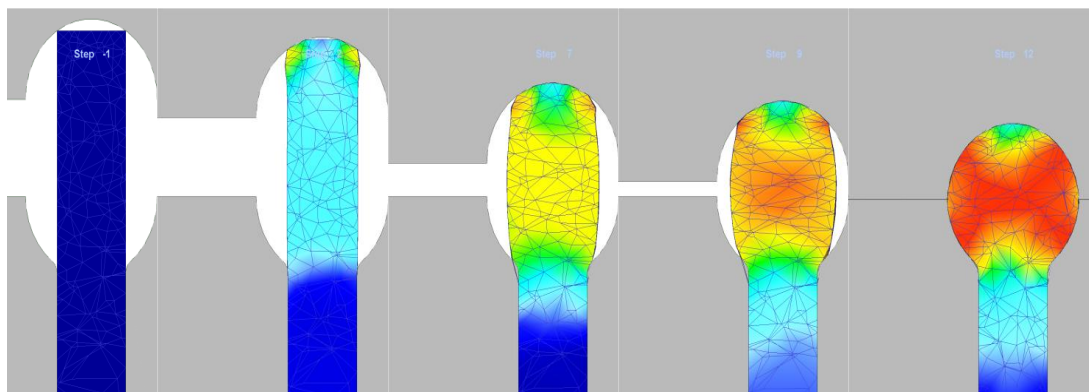


Figure 4. The stages of heading.

The diagram of the dependence of the accumulated degree of shear deformation on the indicator σ/T at point T1 and the metal ductility diagram for 12H18N10T steel [19] are presented in Figure 5. The maximum permissible degree of shear deformation Λ_p is composing 4.33 when $\sigma/T = -0.77$ for 12H18N10T steel. The metal ductility reserve in the “danger zone” is relatively large ($\Lambda_s = 0.26$ when $\sigma/T = -0.77$). This phenomenon is explained by a favorable stress-strain state scheme during sinking strain, which does not provoke an increase in tensile stresses in the “danger zone”.

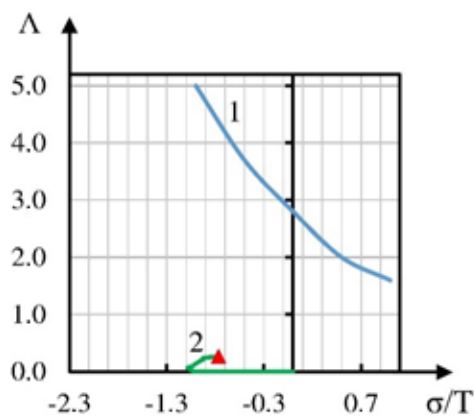


Figure 5. Dependence diagram of Λ on σ/T during heading: 1 – ductility diagram $\Lambda_p = \Lambda_p(\sigma/T)$ for 12H18N10T steel; 2 – dependence curve $\Lambda_i = \Lambda_i(\sigma/T)$ for point T_1 .

The damage at the dangerous point after heading is $\omega_{\Sigma} = 0.029$, which is significantly less than the first micro-destruction criterion ω^* . A favorable stress-strain state scheme occurs in the hearth during almost the entire heading cycle. This scheme is close to the all-round compression scheme. The indicator $\sigma/T < 0$ varies in the range from -0.77 to -1.09 . This is the stress-strain state scheme in accordance with the diagram in Figure 5 assumes “unlimited” ductility of the metal under specified conditions [18]. It is ensuring that there is no metal destruction at the T1 point and vicinity of this point during the heading process. It can be concluded that there is no damage in the form of micropores and microcracks in the “danger zone” after heading. A pilot batch of three plates was made using the proposed technology.

5. Conclusion

The phenomenological model of damage accumulation allowed to estimate the probability of micro-and macro-destruction of metal in the “danger zone” as well as the resource of the ductility for various stress-strain state schemes. It was possible to choose a rational option for making a plate based on the results of damage calculation.

The most suitable for small-scale production of the internal combustion engine mounting plate was recognized as the technological version of the heading on the finished plate. In this case, only one operation is provided – abrasive cutting of the end parts of the plate after heading.

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Acknowledgments

The study was made within the base part of state job in the field of scientific activity № 0836-2020-002.